LA-UR-19-22117

Title: Evaluation of Various Collimators for UF6 Gas Pipe Measurement

Author(s): Swinhoe, Martyn Thomas

Intended for: Report

Issued: 2019-03-11

Evaluation of Various Collimators for UF_6 Gas Pipe Measurement

M. T. Swinhoe

Los Alamos National Laboratory

February 2019

Introduction

On-line gamma measurements of the enrichment of uranium in UF_6 gas in pipes is carried out as part of international safeguards. The 186 keV line from ^{235}U is measured in NaI detectors [1]. One complication in the analysis is that the 186 keV line also comes from the (time-dependent) amount of uranium-bearing material deposited on the interior walls of the pipe. This contribution has to be subtracted before the enrichment of the gas can be calculated. The relative contributions to the total 186 keV count rate from the gas and from the deposit depends on the amount of deposit, but also on the type of collimation/shielding used between the NaI detector and the gas pipe. Several different collimation/shielding designs have been simulated in order to determine which provides the best performance.

Model

These calculations used a simple model in MCNP6 to see if there were significant gains to be made from various collimator options. The model of the pipe was a 60 cm length of 4.0 cm inner diameter and 4.6 cm outer diameter (thickness 0.3 cm). The pipe material was iron (approximating steel) with density 7.87 g/cm^3. The collimator material was tungsten with density 19.35 g/cm^3. The NaI detector was 7.62 cm diameter (3 inch) and 1.27 cm (0.5 inch) thick with density 3.67 g/cm^3. The gas source was UF_6 at a pressure of 25 Torr and a temperature of 300K, with an outer radius of 1.997655 cm, leaving a deposit thickness of 2.345×10^{-4} cm. The deposit was assumed to be UO_2F_2 with a density of 4.263 g/cm^3. This makes the deposit about 1000 $\mu g/cm^2$. Only 186 keV gammas were used as the source. The mass of UF_6 gas in this pipe section was 0.355g. Assuming an enrichment of 5% we have 1.199×10^{-2} g of ^{235}U in the gas and 2.912×10^{-2} g of ^{235}U in the deposit. The emission rate of 186 keV gammas is 4.57×10^4 $\gamma/s/g^{235}U$.

Gaussian energy broadening was not used in order to easily extract the number of 186 keV photons entering the detector. The overall full energy peak contribution at this energy is close to 100% for this thickness of detector [2][1]. Four different geometries were considered: 1) no collimator, 2) a circular 2 cm diameter collimator 3) a 1 cm wide slit collimator that ran the length of the pipe section and 4) (for reference) a no collimator case with the detector closer to the pipe. In the first three cases the distance from the pipe to the front face of the collimator was 1.2 cm; in the latter case the distance was 0.2 cm. In each case one run was made with the gas as a source and one run was made with the deposit as a source.

[1] This is also why it is not important to model any detector structure behind the NaI volume in this case.

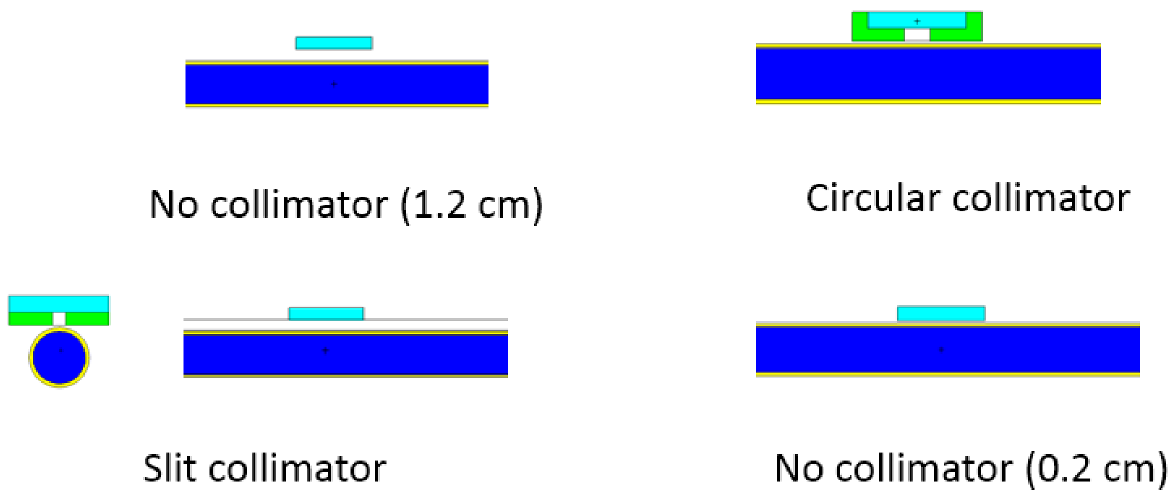

Figure 1 The four different geometries used in this study.

Analysis and Results

For a fixed gas pressure and temperature, the enrichment is proportional to the net count rate (N) obtained by subtracting the background rate (B) from the gross (G) rate. In the real measurement situation the background is composed of 186 keV gammas from the deposit, B_d, 186 keV gammas from places other than the pipe (for example, nearby UF_6 cylinders etc. "environmental background") as well as Compton scattered events caused by higher energy gammas. These are all accounted for in various ways in the analysis. In the current simulation, where we are calculating the benefit from different collimators, the only background considered is that from the deposit (other backgrounds are assumed to be perfectly taken care of). See [3] for a fuller discussion of uncertainties. Therefore we are calculating the uncertainty on the net count rate for each case with contributions from the gross count and the deposit background. (We ignore the issue of the enrichment calibration and assume that the error on the calibration can be made as small as desired by comparison with destructive analysis of samples taken from the process.) The uncertainty on the gross count (G) is the simple statistical uncertainty of the counts, which depends on the counting rate and counting time. The cases here assume a 4 hour counting period. The uncertainty on the deposit background is not a simple square root of the counts but depends on how the background is determined. One method, for example, is to determine the intercept on a plot of counting rate versus gas pressure [3]. We have assigned a fixed percentage of 1% to the uncertainty of the determination of the background for this work, without consideration of which method is used. Therefore we have (using B now for deposit background)

$$N = G - B$$

$$\left(\frac{\sigma_N}{N}\right)^2 = \frac{\sigma_G^2 + \sigma_B^2}{(G - B)^2}$$

and

$$\sigma_G^2 = G/t \qquad\qquad \sigma_B^2 = (fB)^2$$

where t is the measurement time and f is the fractional uncertainty assigned to the determination of the deposit counting rate.

Using these relationships, we obtain the results in Table 1 for the nominal case (gas pressure 25 torr and deposit thickness 1000 μg/cm^2). We see that the performance for the no collimator cases and the slit collimator case are almost identical at around 2%, but the uncertainty from the circular collimator case is somewhat larger at 3%.

Table 1 Counting rate and uncertainties for reference case. The gas and deposit tallies are from MCNP6 and the rsd is the approximate relative standard deviation for each case. The gas/gas column gives the relative efficiency for the gas source in each system. The final column is the relative uncertainty on the net counting rate.

System	Gas tally	Deposit tally	rsd	Gas/ Dep tally	Gas/ Gas	Gas cps	Dep cps	Gas /Dep	σ_G	σ_B	Total rel error
No collimator	1.26×10^{-2}	1.08×10^{-2}	0.0003	1.17	0.804	6.93	14.41	0.48	3.85×10^{-2}	1.44×10^{-1}	2.2%
Circular collimator	6.96×10^{-4}	5.58×10^{-4}	0.0013	1.25	0.044	0.38	0.74	0.51	8.84×10^{-3}	7.43×10^{-3}	3.0%
SLIT collimator	2.34×10^{-3}	1.65×10^{-3}	0.0008	1.42	0.149	1.28	2.20	0.58	1.56×10^{-2}	2.20×10^{-2}	2.1%
NC (close)	1.57×10^{-2}	1.35×10^{-2}	0.0003	1.16	1.000	8.62	18.00	0.48	4.30×10^{-2}	1.80×10^{-1}	2.1%

Although the MCNP calculations were carried out for a particular gas pressure and deposit thickness because the attenuation in the gas and deposit is relatively small, we can extrapolate to other gas pressures and deposit thicknesses simply by changing the relative source strengths, without introducing large errors. The results for cases with 10 and 50 Torr pressure and 100 and 1000 μg/cm^2, together with the reference case, are shown in Table 2 and plotted in Figure 2.

Table 2 Uncertainties Calculated from Reference Case and Extrapolations (see text for explanation of cases)

Case		Uncertainty			
Gas Pressure torr	Deposit Thickness μg/cm^2	No collimator	Circular Collimator	Slit collimator	No collimator (close)
25	1000	2.2%	3.0%	2.1%	2.1%
10	100	0.8%	2.6%	1.5%	0.8%
10	1000	5.3%	7.1%	5.1%	5.3%
50	100	0.3%	1.0%	0.5%	0.2%
50	1000	1.1%	1.7%	1.1%	1.1%

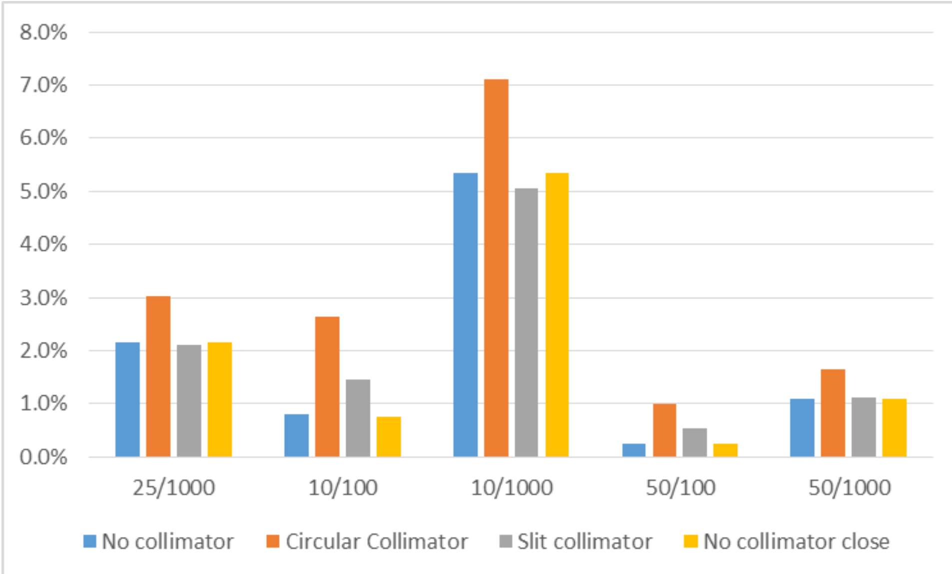

Figure 2 Graphical presentation of the results from Table 2 Uncertainties Calculated from Reference Case and Extrapolations (see text for explanation of cases)

We see a similar trend to the reference case over the different gas/deposit ratios as for the reference case. The circular collimator performance is somewhat worse than the other three cases. It is also clear that for large deposit and low gas pressure all systems have significantly worsened performance.

The values of the overall uncertainties are determined by contributions from counting statistics (bigger contributions in the case of lower efficiency systems) and from the deposit correction (better discrimination between gas and deposit helps.) Therefore the results are affected by the choice of counting time and deposit determination error. The latter has been treated here simplistically by fixing the magnitude without considering the method or background averaging time. A larger counting time reduces the differences between the systems because counting statistics make a bigger contribution in the case of the circular collimator because of its low absolute efficiency and so brings its results closer to the others where the statistical contribution is already small. Halving the deposit determination error to 0.5% reduces the overall error on the reference case by a factor of 2 for all systems except for the circular collimator case, which only improves a little.

The contribution from the environmental background (ignored in this analysis) can be made small by suitable shielding around the detector. But its effect on the uncertainty would be worse for the low efficiency systems because of their smaller signal counting rates.

Conclusions

We have carried out some simulation studies to determine if the performance of an online enrichment measurement could be improved by changed collimation. The simple conclusion is that there is no benefit to be obtained by either a small circular collimator or a slit collimator that runs along the axis of the pipe. Also the separation distance between the pipe and the detector in the uncollimated case has only a very small effect.

References

1. L. E. Smith and A.R. Lebrun *Design, Modeling and Viability Analysis of an Online Uranium Enrichment Monitor* 2011 IEEE Nuclear Science Symposium Conference Record, 2011

2. H. O. Anger and D. H. Davis *Gamma-ray Detection Efficiency and Image Resolution in Sodium Iodide*. Review of Scientific Instruments 35 (1964) 693

3. J. H. Ely, M.T. Swinhoe, A. Favalli and J.R. Younkin, *Performance Envelope and Precision of the OLEM* Pacific Northwest National Laboratory Report PNNL-27811 August 2018